AMENDMENTS TO THE SPECIFICATION:

Please replace the paragraph beginning on page 5, line 24 and ending on page 6, line 11 with the following amended paragraph:

There are two sets of antenna array characteristics that are preferably used for DOA estimation in accordance with the preferred embodiment of the present invention. The first antenna array characteristic is the positioning of the individual antenna elements within the array. The positioning of the individual antenna elements within the array yields phase differences between the signals received on each of the antennas, which are a function of the antenna positions and the DOA. (See, Hamid Krim and Mats Viberg, Two Decades of Array Signal Processing Research, IEEE Signal Processing Magazine, Vol. 13, No. 4, July 1996, for a description of the relationship between phase differences and DOA, which is hereby incorporated by reference.) The vector-valued collection of the phase differences can be expressed as:

$$a(\theta)=[a\cancel{1}_{\underline{1}}(\theta)\ a\cancel{2}_{\underline{2}}(\theta)\ \ldots\ a\cancel{N}_{\underline{N}}(\theta)]\cancel{T}^{\underline{T}} \quad (1)$$

Where $\theta$ is the DOA, $a\cancel{i}_{\underline{i}}(\theta)=\exp(j\varphi i(\theta))$, $\varphi i(\theta)$ is the complex valued phase shift of antenna element i, and j=sqrt(-1).

Please replace the paragraph beginning on page 6, line 12 and ending on page 6, line 23 with the following amended paragraph:

The second antenna array characteristic that enables the estimation of the DOA is the antenna directivity (i.e., the patterns of the antenna elements of the array). Each antenna element of the array has a gain and phase shift associated with each DOA. The vector-valued collection of the antenna element directivities for an antenna array can be expressed as:

$$b(\theta)=[b\cancel{1}_{\underline{1}}(\theta)\ b\cancel{2}_{\underline{2}}(\theta)\ \ldots\ b\cancel{N}_{\underline{N}}(\theta)]\cancel{T}^{\underline{T}} \quad (2)$$

Where $b\cancel{i}_{\underline{i}}(\theta)$ is the directivity pattern of antenna element i. The directivity patterns of the antenna elements can be modified from the isolated value for each antenna element using a mutual coupling configuration between the elements. This mutual coupling configuration between the elements can be utilized in accordance with the present invention with the use of directivities measured for the antenna elements while positioned in the desired array geometry.

Please replace the paragraph beginning on page 6, line 24 and ending on page 7, line 10 with the following amended paragraph:

The combination of the two characteristics due to the antenna element positions and directivities forms a vector-valued response function commonly referred to as the composite array manifold. The composite array manifold (c(θ)) can be produced with a Hadamard product (i.e., element-wise product) of the two characteristics of the array and expressed as:

A3

$$c(\theta) = a(\theta)\oplus b(\theta) = [a\cancel{1}_{\underline{1}}(\theta)b\cancel{1}_{\underline{1}}(\theta)\ a\cancel{2}_{\underline{2}}(\theta)b\cancel{2}_{\underline{2}}(\theta)\ \ldots\ a\cancel{N}_{\underline{N}}(\theta)b\cancel{N}_{\underline{N}}(\theta)]\cancel{T}^{\underline{T}} \qquad (3)$$

Where ⊕ is the Hadamard product, a(θ) is the vector-valued collection of the phase differences of equation (1) and b(θ) is the vector-valued collection of the antenna element directivities for an antenna array of equation (2). While the foregoing composite array manifold production is used in this detailed description of the drawings, any number of techniques can be used in accordance with the present invention to exploit the different features of array manifolds for DOA estimation.

Please replace the paragraph beginning on page 7, line 11 and ending on page 7, line 22 with the following amended paragraph:

With particular reference to the enlarged view 52 of FIG. 3, the differential electrical phase (ϕ) of the signal from the remote unit is a function of the DOA (θ), separation distance (d) 54 between the first antenna 34 and second antenna 36 forming one of the antenna pair (i.e., inter-element spacing), and wavelength (λ) of the signal as follows:

A4

$$\phi(\theta) = \phi\cancel{2}_{\underline{2}}(\theta)-\phi\cancel{1}_{\underline{1}}(\theta) = 2\pi(d/\lambda)\sin(\theta) \qquad (4)$$

While a separation distance (d) 54 that is approximately less than one-half the wavelength (λ) of the signal frequency produces a unique mapping between the differential electrical phase (ϕ) and the DOA (θ) within a one hundred and eighty degree (180°) range, a separation distance (d) 54 that is approximately greater than or equal to one-half of the wavelength (λ) (i.e., irregular antenna element spacing) introduces ambiguities in the mapping of the differential electrical phase (ϕ) observed by the receiving antenna elements to the DOA (θ).

Please replace the paragraph beginning on page 9, line 18 and ending on page 10, line 9 with the following amended paragraph:

A5

The RF signal 32 received by the first antenna 34 and the second antenna 36, converted by the first RF converter 70 and second RF converters 74, and digitized with the first A/D converter 76 and second A/D converter 78 includes multiple scattered rays produced by multi-path scattering of the RF signal 32 during transmission from the remote unit, with each ray of the multiple scattered rays being a separate multi-path reflection of the RF signal 32. The multiple scattered rays produced by the multi-path scattering are generally arriving from different directions, at different time delays, and generally have different complex valued amplitudes (i.e., gain and phase components). Therefore the RF signal 32 received from the remote unit 22 generally includes multiple scattered rays having different complex amplitudes, times of arrival, and directions of arrival. The collection of voltages produced by each scattered ray ($r\cancel{i}_{\underline{i}}$) on the antenna array elements can be expressed as:

$$r\cancel{i}_{\underline{i}}(t) = c(\theta\cancel{i}_{\underline{i}})s(t-\tau\cancel{i}_{\underline{i}}) \qquad (5)$$

Where $\tau\cancel{i}_{\underline{i}}$ is the time delay of ray i, $\theta\cancel{i}_{\underline{i}}$ is the DOA of ray i, s(t) is the transmitted signal and $c(\theta\cancel{i}_{\underline{i}})$ is the composite array manifold of equation (3). A model for the vector-valued received signal r(t) with multi-path scattering incorporating M rays can be expressed as:

$$r(t) = r\cancel{1}_{\underline{1}}(t) + r\cancel{2}_{\underline{2}}(t) + \ldots + r\cancel{M}_{\underline{M}}(t) \qquad (6)$$

Please replace the paragraph beginning on page 11, line 13 and ending on page 12, line 5 with the following amended paragraph:

A6

More particularly, a first prompt ray 100 and a first plurality of echo rays 102 result for each in-phase (I) and quadrature phase (Q) component of the first demodulated signal 96 and a second prompt ray 104 and second plurality of echo rays 106 result for each in-phase (I) and quadrature phase (Q) component of the second demodulated signal 98. The first and second prompt rays (100,104) and first and second plurality of echo rays (102,106) generally have different amplitudes, DOAs and time delays. In a preferred embodiment, the despreading and demodulation functions isolate the plurality of time-delayed rays received at the antenna array. A matrix-valued signal (R) results from the despreading and demodulation, contains representations of the scattered plurality of rays (100,102,104,106) of the first and second demodulated signals (96,98) and can be expressed as:

$$R = [\ c(\theta\cancel{1}_{\underline{1}})h(\tau\cancel{1}_{\underline{1}})\ c(\theta\cancel{2}_{\underline{2}})h(\tau\cancel{2}_{\underline{2}})\ c(\theta\cancel{3}_{\underline{3}})h(\tau\cancel{3}_{\underline{3}})\ ] = [r\cancel{1}_{\underline{1}}\ r\cancel{2}_{\underline{2}}\ r\cancel{3}_{\underline{3}}] \qquad (7)$$

The first column $(r\cancel{1}_{\underline{1}})$ of the matrix-valued signal (R) represents the plurality of prompt rays (100,104) received by the antenna array. The subsequent columns $(r\cancel{2}_{\underline{2}},r\cancel{3}_{\underline{3}},r4_{\underline{4}}\ldots)$ represent the subsequent time-delayed echoed rays (102, 106) as received by the antenna array. The scaling values $(h(\tau\cancel{i}_{\underline{j}}))$ represent a scaling due to the time delay of the echoes that is common across substantially all antenna elements. The values contained in the matrix-valued signal (R) are provided to a signal combiner 108, decoder 110 and DOA computer 112 for subsequent processing.

A6

Please replace the paragraph beginning on page 12, line 21 and ending on page 13, line 4 with the following amended paragraph:

Referring to FIG. 9, the DOA computer 112 is shown in greater detail, which is configured to estimate a DOA. The DOA computer 112 includes a ray selector 114, difference calculator 116 and angle estimator 118. The ray selector 114 receives the demodulated signals (96,98) having the matrix-valued signals (R) from the demodulators and selects the prompt rays $(r\cancel{1}_{\underline{1}}=[r\cancel{11}_{\underline{11}}\ r\cancel{12}_{\underline{12}}]\cancel{T}^{\underline{T}})$ of the matrix-valued signal (R) or one of the subsequent time-delayed echoed rays $(r\cancel{i}_{\underline{i}}=[r\cancel{i1}_{\underline{i1}}\ r\cancel{i2}_{\underline{i2}}]T)$ for DOA estimation. The selected rays $(r\cancel{i}_{\underline{i}})$ 100 are provided to the difference calculator 116 for determination of an amplitude difference 120 and a phase difference 122 between the values of the selected rays $(r\cancel{i}_{\underline{i}})$ 100 for the two antenna elements (e.g., $r\cancel{i1}_{\underline{i1}}$ and $r\cancel{i2}_{\underline{i2}}$).

A7

Please replace the paragraph beginning on page 13, line 5 and ending on page 13, line 20 with the following amended paragraph:

Referring to FIG. 10, the difference calculator 116 is shown in greater detail. The first value $(r\cancel{i1}_{\underline{i1}})$ of the selected rays 100 is provided to a first magnitude calculator 124 and a first phase calculator 126 and the second value $(r\cancel{i2}_{\underline{i2}})$ of the selected rays 100 is provided to a second magnitude calculator 128 and a second phase calculator 130. The first magnitude calculator 124 and second magnitude calculator 128 compute the magnitude of the first value $(|r\cancel{i1}_{\underline{i1}}|\cancel{2}^{\underline{2}})$ 132 and the magnitude of the second value $(|r\cancel{i2}_{\underline{i2}}|2)$ 134, respectively. The magnitude of the first value $(|r\cancel{i1}_{\underline{i1}}|\cancel{2}^{\underline{2}})$ 132 and magnitude of the second value $(|r\cancel{i2}_{\underline{i2}}|\cancel{2}^{\underline{2}})$ 134 are provided to a magnitude difference calculator 136 that produces the amplitude difference 120 between the first value $(r\cancel{i1}_{\underline{i1}})$ and the second value $(r\cancel{i2}_{\underline{i2}})$ (i.e., $(|r\cancel{i1}_{\underline{i1}}|\cancel{2}^{\underline{2}}/|r\cancel{i2}_{\underline{i2}}|\cancel{2}^{\underline{2}})$ or (10

A8

A8

$\log\cancel{10}_{\underline{10}}(|r\cancel{i1}_{\underline{i1}}|\cancel{2}^{\underline{2}})$-10$\log\cancel{10}_{\underline{10}}(|r\cancel{i2}_{\underline{i2}}|\cancel{2}^{\underline{2}})$)). In addition, the first phase calculator 126 and second phase calculator 130 compute the phase of the first value ($\angle r\cancel{i1}_{\underline{i1}}$) 140 and phase of the second value ($\angle r\cancel{i2}_{\underline{i2}}$) 142, respectively, which are provided to a phase difference calculator 144 that produces the phase difference 122 between the first value ($r\cancel{i1}_{\underline{i1}}$) and the second value ($r\cancel{i2}_{\underline{i2}}$). The phase difference 122 is provided to the angle estimator 118 for calculation of multiple DOA estimates and the amplitude difference 120 is also provided to the angle estimator 118 for selecting one of the multiple estimates as shown in FIG. 9.

Please replace the paragraph beginning on page 13, line 21 and ending on page 14, line 2 with the following amended paragraph:

A9

Referring to FIG. 11, the angle estimator 118 is shown in greater detail. The magnitude difference is passed to a first DOA solution estimator 124, which is used to compute a first DOA estimate 126 ($\theta\cancel{1}_{\underline{1}}$'). The first DOA estimate 126 ($\theta\cancel{1}_{\underline{1}}$') can be computed with any number of techniques, including the methods described in U.S. Patent 5,786,791, issued to Eugene J. Bruckert on July 28, 1998 and assigned to Motorola, Inc., which is hereby incorporated by reference.

Please replace the paragraph beginning on page 14, line 9 and ending on page 14, line 24 with the following amended paragraph:

A10

The phase calibration 132 can be calculated using any number of techniques. For example, as can be appreciated by one of ordinary skill in the art, the selected column ($r\cancel{i}_{\underline{i}}$) 100 for the two antenna elements can be expressed in greater detail as follows:

$$r\cancel{i}_{\underline{i}} = [\; c\cancel{1}_{\underline{1}}(\theta\cancel{i}_{\underline{i}})\; c\cancel{2}_{\underline{2}}(\theta\cancel{i}_{\underline{i}})\; ]\cancel{T}^{\underline{T}}\, h(\tau\cancel{i}_{\underline{i}}) \quad (8)$$

$$\text{or } r\cancel{i}_{\underline{i}} = [a\cancel{1}_{\underline{1}}(\theta\cancel{i}_{\underline{i}})b\cancel{1}_{\underline{1}}(\theta\cancel{i}_{\underline{i}})\; a\cancel{2}_{\underline{2}}(\theta\cancel{i}_{\underline{i}})b\cancel{2}_{\underline{2}}(\theta\cancel{i}_{\underline{i}})]\cancel{T}^{\underline{T}}\, h(\tau\cancel{i}_{\underline{i}}) \quad (9)$$

Where $b\cancel{1}_{\underline{1}}(\theta\cancel{i}_{\underline{i}})$ and $b\cancel{2}_{\underline{2}}(\theta\cancel{i}_{\underline{i}})$ are the antenna element directivity of the first antenna element and second antenna element, respectively (i.e., the antenna array element directivity data 128), $h(\tau\cancel{i}_{\underline{i}})$ is a complex amplitude for the selected time delayed echo which is common to the antenna elements, and $ak(\theta\cancel{i}_{\underline{i}})$ represents the complex valued phase shift observed on antenna k due to the positioning of antenna element k and the DOA $\theta\cancel{i}_{\underline{i}}$, as previously discussed in this detailed description of the drawings. In a preferred embodiment, the phase

difference calibration 132 ($\phi'$) is the phase difference between the directivities of the antenna array elements measured at the first DOA estimate 126 ($\theta\cancel{1}_{\underline{1}}'$), which can be expressed as follows:

A10

$$\phi' = \angle(b\cancel{2}_{\underline{2}}(\theta\cancel{1}_{\underline{1}}')/ b\cancel{1}_{\underline{1}}(\theta\cancel{1}_{\underline{1}}')) \qquad (10)$$

Where $b\cancel{2}_{\underline{2}}(\theta\cancel{1}_{\underline{1}}')$and $b\cancel{1}_{\underline{1}}(\theta\cancel{1}_{\underline{1}}')$ are the antenna element directivities of the first antenna element and second antenna element at the first DOA estimate 126 ($\theta\cancel{1}_{\underline{1}}'$), respectively.

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Please replace the paragraph beginning on page 15, line 9 and ending on page 19, line 8 with the following amended paragraph:

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A11

The ambiguous DOA solution generator 140 calculates K ambiguous DOA values 142 ($\theta''=[\theta\cancel{1}_{\underline{1}}''\ \theta\cancel{2}_{\underline{2}}''\ \theta\cancel{K}_{\underline{K}}'']\cancel{T}^{\underline{T}}$), preferably calculates the majority of ambiguous DOA values, and most preferably calculates substantially all or all the ambiguous DOA values, which yield the observed calibrated phase difference 136 ($\varphi''$) for the given antenna array element geometry data 138. For example and with reference to FIG. 5, the multiple ambiguous DOA values 142 (i.e., the K ambiguous DOA values) can be selected with a reverse table-lookup operation of the ambiguous DOA values 142 ($\theta''=[\theta\cancel{1}_{\underline{1}}''\ \theta\cancel{2}_{\underline{2}}''\ \theta\cancel{K}_{\underline{K}}'']\cancel{T}^{\underline{T}}$) along the DOA axis 59 that yields the observed calibrated differential electrical phase along calibrated differential electrical phase axis 57. Referring to FIG. 11, the ambiguous DOA values ($\theta''=[\theta\cancel{1}_{\underline{1}}''\ \theta\cancel{\theta}_{\underline{2}}''\ \theta\cancel{K}_{\underline{K}}'']\cancel{T}^{\underline{T}}$) 142 and the first DOA estimate 126 ($\theta\cancel{1}_{\underline{1}}'$) are provided to the final DOA estimator 144.

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